BELLCOMM, INC.

COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE – Communications and Tracking for Reentry and Recovery Phases of Apollo Lunar Landing Mission

TM – 66-2021-2

FILING CASE NO(S) – 320

DATE – March 29, 1966

AUTHOR(S) – R. K. Chen
J. E. Johnson
R. L. Selden

FILING SUBJECT(S) – (ASSIGNED BY AUTHOR(S)) – C-Band Radar Modifications for Apollo Reentry Ship
Communication and Tracking for Apollo Reentry and Recovery Phases

ABSTRACT

The operational support for the reentry and recovery phases of an Apollo lunar landing mission has been evaluated to determine the advisability of implementing the modifications of the C-band radar system on the Apollo reentry ships proposed by GSFC.

After examing the capabilities and limitations of the recovery aircraft and reentry ships presently planned for the operational support of these phases, it is concluded that the proposed C-band radar system modifications should be implemented. The modified C-band radar system would:

1. serve as an acquisition aid to the Unified S-band system on the reentry ship to assure two-way voice communication and recording of telemetry from the CM while it is not in communication blackout, and

2. provide gross landing point prediction data of the CM to the recovery force, which would not otherwise be available.

It is also concluded that a single reentry ship on station would be capable of providing communication and tracking coverage for a given landing area for about 90% of the spread of presently planned reentry trajectories.

SEE REVERSE SIDE FOR DISTRIBUTION LIST

BELLCOMM, INC.

TM— 66-2021-2

DISTRIBUTION

COMPLETE MEMORANDUM TO

CORRESPONDENCE FILES:

OFFICIAL FILE COPY

plus one white copy for each additional case referenced

TECHNICAL LIBRARY (4)

E. E. Christensen/MO
J. K. Holcomb/MAO
T. A. Keegan/MA-2
J. T. McClanahan/MAO
L. M. Robinson/OTDA

C. A. Beers/MSC
H. E. Clements/MSC
J. D. Hodge/MSC
C. C. Kraft/MSC
E. F. Kranz/MSC
H. C. Kyle/MSC
J. Lindsey/MSC
D. H. Owens/MSC
L. Packham/MSC
P. Vavra/MSC

R. McCaffery/GSFC
F. Vonbun/GSFC

W. J. Benden
I. Bogner
J. P. Downs
J. J. Hibbert
J. A. Hornbeck
B. T. Howard
H. Kraus
T. F. Loeffler
J. P. Maloy
C. R. Moster

COVER SHEET ONLY TO

COMPLETE MEMORANDUM TO

H. Pinckernell
J. T. Raleigh
I. M. Ross
P. F. Sennewald
G. H. Speake
W. Strack
T. H. Thompson
R. L. Wagner
A. G. Weygand
Department 1023

BA – 146 (8-64)

BELLCOMM, INC.

SUBJECT: Communication and Tracking for Reentry and Recovery Phases of Apollo Lunar Landing Mission. Case 320

DATE: March 29, 1966

FROM: R. K. Chen
J. E. Johnson
R. L. Selden

TM-66-2021-2

TECHNICAL MEMORANDUM

I. Introduction

A proposal has been made by Goddard Space Flight Center (GSFC) to modify the present C-band radar system (FPQ-10) on the Apollo reentry ships. The modification was discussed at a meeting held at MSC on March 9, 1966. This memorandum examines the operational support for the reentry and recovery phases of lunar landing missions in order to evaluate the advisability of implementing the modifications proposed by GSFC.

A brief discussion on the reentry trajectories is given in Section II, and the operational requirements for the reentry and recovery phases are discussed in Section III. Section IV is a summary of the present system implementation planned for the reentry and recovery phases, and its expected performance and limitations, including the effects of equipment failure. The expected improvement in C-band radar system performance, after modifications, and its influence on the overall operational effectiveness are also included in Section IV. The deployment strategy for reentry ships to provide optimum operational support throughout the lunar month is discussed in Section V. Section VI contains the conclusions and recommendations.

II. Reentry Trajectories

The reentry trajectories of the Apollo Command Module (CM) returning from a lunar mission are shaped by three major constraints; they are:

1. capturing of the spacecraft by the Earth's atmosphere on the first attempt to insure a landing,

2. not exceeding a certain aerodynamic loading during the reentry, and

3. not exceeding a certain heat load and heat rate during the reentry.

These constraints are satisfied by appropriate design of the reentry guidance and navigational equipment on the spacecraft based on the lift to drag (L/D) characteristic of the CM, the reentry velocity, the reentry flight path angle, and the relative position of the reentry point and the designated landing point.

Because of the possible variations of the reentry point, the reentry velocity, and the aerodynamic characteristics of the spacecraft, a range of reentry trajectories are possible. In case of equipment malfunction onboard the spacecraft, the CM may miss the landing point in both the down range and lateral range directions. Some typical trajectories for L/D of 0.3 and 0.4 are shown in Figures 1-6, and the lateral range variations are shown in Figure 7[(1)]. It should be noted that the current requirements state that the reentry range will be between 1500 and 3500 nm. from the reentry point at 400,000 ft altitude and the L/D of the CM will be within 0.3 and 0.38.[(2)]

---

(1) "Apollo Navigation Ground and Onboard Capabilities," Apollo Navigation Working Group, Technical Report No. 65-AN-2.0, September 1, 1965.

(2) "Apollo Program Specification" Specification No. SE005-001-1 May, 1965. (Confidential).

The shape of the reentry trajectory has two major effects on the planning of communications and tracking coverage during the reentry and recovery phases; namely, (1) RF signal impairment (blackout) resulting from the plasma medium surrounding the spacecraft, and (2) the acquisition of the spacecraft while it is in blackout or after it emerges from the blackout. The RF blackout boundary during reentry for the CM is a function of the altitude and velocity of the CM and the ablation products from the CM heat shield. It is not possible at this time to determine the blackout boundaries for different RF frequencies with certainty. A gross estimate, from available data, of the blackout boundary for the S-band frequency would be as follows:

1. between 320,000 ft and 260,000 ft altitude during the initial phase of the reentry, and

2. between 260,000 ft and 150,000 ft altitude during the terminal phase of the reentry.

Two problems are involved with the acquisition of the CM by an Earth station, such as a ship. One concerns the RF blackout phenomenon which dictates the decision of using either transponder tracking or plasma sheath tracking. The other concerns the possible dispersion of the CM from its nominal trajectory as indicated in Figure 7. It is clear that the possible dispersion in lateral range becomes larger as the CM travels down range which would require a larger search area for the acquisition system.

III. Operational Requirements

Three major ground support functions need to be performed during the reentry and recovery phases, namely:

1. recovery of the crew and spacecraft, within a reasonable time period after landing,

2. two-way voice communication with the CM, and

3. reception and recording of telemetry from the spacecraft for post mission analysis.

In order to satisfy the first functional requirement, the landing point of the CM needs to be predicted by either tracking the CM from a reentry ship or using direction finding techniques presently planned by the recovery aircraft. The second and third function could be satisfied by a properly located reentry ship or possibly by using Apollo instrumented aircraft planned for use during the injection phase provided that the CM is not in the S-band blackout region.

IV. System Implementation

Three major systems are planned for the operational support of the reentry and recovery phases. These systems are discussed in this section in terms of their presently planned capabilities and proposed improvements. The limitations of each system are also discussed. The recovery ships located near the expected landing point are not considered here because of their limited communications and tracking capabilities.

A. Recovery Aircraft

According to the present planning, nine recovery aircraft will be deployed over the expected CM landing footprint which is approximately 2,000 nm. long and 600 nm. wide. These aircraft rely on the signal from the radio equipment of the CM for direction finding, but they would not have the capability of communicating with the CM until it has deployed its parachutes (around 12,000 ft altitude). The operation of the recovery aircraft can be divided into three separate phases as follows:

1. From reentry point (400,000 ft altitude) to main parachute deployment (12,000 ft altitude) - The signal radiated from the CM during this period would be from the Unified S-Band System. During part of this period, the S-band signal would not be available to the aircraft because of the blackout caused by the plasma sheath. After the CM emerges from the blackout region, the S-band system performance is expected to be degraded from the charring of the ablative cover over the S-band omni-antenna elements. The present estimate of the charring loss, supplied by MSC/IESD, is 30 db, with a possible range from 1 to 50 db. Using the 30 db loss figure would reduce the range capability of the aircraft by a factor of 32 to approximately 35 nm. (see Table I) which would drastically restrict the DF capability of these aircraft. The maximum charring loss that can be tolerated by the aircraft for 500 nm. range is about 7 db.

Two additional problems may further restrict the usefulness of the recovery aircraft during this period; one is the possible failure of the CM S-band transmitting equipment, and the other is the S-band antenna switching problem. In case of the failure of one of the S-band transponders or power amplifiers, the crew would not be aware of such a situation as there are no onboard failure indications displayed to them. Consequently, there will be no indication for the crew to switch to the redundant transponder or power amplifier if the one in use fails. In other phases of the mission, an MSFN station would alert the crew to their lack of transmission.

The CM carries four S-band antennas which are anticipated to be manually switched, providing omni-directional coverage. The particular antenna used is selected by the crew based on received signal strength from the several antennas. Since the recovery aircraft does not radiate a signal to the spacecraft, the crew would not have any indication of the right choice of the four antenna elements to radiate a signal toward the recovery aircraft. Moreover, because of the limited coverage area from one antenna element of the CM, there is a high probability that only one recovery aircraft would be within the CM antenna beamwidth at any particular instance, which is unsatisfactory for direction finding purposes.

2. From main parachute deployment to splash down - The RF signals radiated from the CM during this period are the VHF voice (296.8 mc) and the VHF beacon (243.0 mc). The major problems resulting in loss of the spacecraft DF could be a recovery aircraft failure when the CM is in a single aircraft coverage area, and the limited search time available to the aircraft. Other possible problems are the failure of the VHF antenna on the CM, and the activation of the transmitters in case of crew disability.

3. After splash down - the RF signals radiated from the CM after splash down are the VHF signals described above and the addition of a HF signal (10.006 mc). During this period the operation becomes the standard air/sea rescue operation.

   Additional problems besides the longer search time required are the possibilities of the sinking of the CM because of damage or the failure of the CM to up-right itself, particularly in a rough sea. Under such circumstances, there would be no RF signal radiating from the CM to expedite recovery operations.

B. Reentry Ship

The reentry ship has two major communication and tracking systems, the USB system and the C-band tracking system. The capabilities of these systems and their limitations are discussed below.

1. Unified S-band (USB) System - The basic parameters of the USB system are, 12 ft antenna, 2 db noise figure receiver, and 2 Kw transmitter power. The system is capable of performing both the tracking and the communication (voice and telemetry) functions whenever the CM is not in the blackout region. The performance of the USB system, including 30 db signal loss from charring of the CM antenna, for various modes of operation is calculated in Appendix A. It is seen that the only mode possible on the down link is the emergency voice plus 1.6 kbps telemetry or ranging by itself. On the other hand if the charring loss is less than 27 db, normal ranging, voice and 1.6 kbps TM can be provided.

   The major problem with the USB system on the reentry ship is its lack of acquisition capability. In this case, the acquisition problem is mechanical angle scanning, frequency searching, and phase locking of the receivers. It is believed that the USB system by itself, without any a priori knowledge of the CM location, would not be capable of acquiring the CM with any high degree of probability during its visibility period which is limited by the expected blackout

The other problem with the S-band system is again the omnidirectional antenna element switching onboard the CM. There are actually two parts to this problem, one occurs during the initial acquisition phase and the other occurs after acquiring and lock-on while the CM executes roll maneuvers to position its lift vector prior to final descent. During the initial acquisition phase, it would be necessary for the crew to determine on which antenna element the RF signal is being transmitted to them from the ship. Once acquired, it may be necessary to switch the antenna elements again in order to maintain contact with the ship. Whenever antenna switching is necessary, the ship receiver may lose lock which would require going through the frequency and phase lock procedure with a resulting loss of valuable communication time.

One interesting side effect during the time when the CM is maintaining contact with the ship is the high probability of disrupting the DF operation of the recovery aircraft. This comes about as the result of the limited coverage of the CM antenna elements so that unless the aircraft is within the antenna coverage cone, it would not be able to receive any S-band signal.

2. C-band tracking radar - The present C-band tracking radar on the reentry ships is the FPQ-10 radar system. This system is somewhat limited in its skin tracking capability; its range performance is estimated to be 126 nm. for a 1 m^2 target as shown in Table II. Since the radar cross section of the plasma enclosed CM has not been well defined, a firm number is not available. Using the 10 m^2 which was estimated by NAA[3] corresponding to a radar incident angle of approximately 30° as shown in Figure 8, the present system would not have the desired range performance,

---

(3) "Final Report on Apollo Plasma Reentry Studies," NAA Report No. SID63-746, July 5, 1963.

which is in the order of 300 nm. Another major limitation of the present shipboard system is its acquisition capability. The acquisition capability is limited in two respects, one is an approximate time limit of about two minutes in scanning at the maximum scanning rate, and the other is the time required to scan the required acquisition volume even at the maximum rate.

The modifications proposed by GSFC for the C-band radar on the reentry ship are as follows:

a. increase peak transmitting power from 1 Mw to 3 Mw,

b. increase antenna diameter from 12 ft to 16 ft,

c. improve the scanning capability of the system including a triple antenna feed so that it would be capable of scanning a 6° x 23° window in 5 seconds, and

d. change receiver front end to a cooled parametric amplifier.

Table III is a calculation of the range performance of the modified radar. It is seen that the modified system is capable of tracking a 1 m^2 target to a range of 235 nm. and a 10 m^2 target to a range of 420 nm. Perhaps the more significant improvement is its acquisition capability, it has been estimated by GSFC that the probability of detection at 280 nm. is now 99.5%[(4)] on the basis of 1 m^2 target with the ship located at 840 nm. down range from the reentry point. With this improvement, it is now possible for the C-band radar to perform two important functions, they are:

---

(4) J. R. Moore, "Apollo Entry Radar Acquisition Study," GSFC Report No. X-513-65-225, May 28, 1965.

a. serving as the acquisition aid to the USB system, and

b. providing gross impact point prediction data to the recovery operation even when tracking the plasma sheath of the CM.

C. Apollo Instrumented Aircraft

The Apollo Instrumented Aircraft used for lunar injection coverage could be deployed for reentry communication purposes. The aircraft are capable of transmitting and receiving voice and TM on the USB system. These aircraft are subjected to all the problems of the USB system on the reentry ship plus the additional shortcomings of a reduced antenna gain (30 db instead of 36 db for the reentry ship), reduced output power (100 w), and higher receiver noise figure (4 db). A brief calculation shows that the maximum tolerable charring loss is approximately 20 db for voice communication from the aircraft to the CM and approximately 25 db for voice and TM communication from the CM to aircraft at 500 nm. range.

V. Reentry Ship Deployment

There are two aspects to reentry tracking ship deployment, namely, determination of the optimum ship location relative to the reentry point, and determination of relocation strategy to cover differing possible positions of the reentry point relative to the Earth's surface.

The need for both C-band tracking and S-band coverage of the CM dictates a location of the ship between the pull-up and the top of the ballistic lob. Using Figure 5 as a representative reentry altitude profile, it is possible to locate a ship as far as 810 nm. downrange from the reentry subpoint and still see the CM at pull-up. This assumes a 1.5° minimum elevation angle, which corresponds to about half the total beamwidth of the three beam C-band search pattern. For the profile shown in Figure 5, this location would permit about two minutes of C-band tracking and about one and one-half minutes of S-band coverage, assuming instantaneous acquisition. The approximate times and locations of contact and loss would be as follows:

	Ground Range (nm.)				
	from Reentry Point	from Ship	Altitude (ft)	Elevation(°)	Time* (sec)
C-band contact	500	310	185,000	1.5	90
End of blackout	960	150	260,000	16	210
S-Band loss	1310	500**	320,000	2	300

---

* Measured from reentry time.
** Assumed range-limited by 30 db charring loss.

Note that the horizon limitations and the expected maximum range performance of the upgraded C-band radar are about equal, as are the horizon limitations and the char-attenuated range capability of the S-band system. Thus, the proposed ship location appears to be about optimum for the expected conditions.

While the nominal reentry point location relative to the Earth's surface will be known at the time of launch from the Earth, some flexibility must be allowed to adjust for minor deviations from the nominal so as to not over-constrain the mission. At the same time, it is obviously impossible to provide coverage for all conceivable reentries. The chief ground rules adopted for this look at ship deployment strategy are: reentry-to-touchdown ranges of 1500 to 3500 nm., and inclinations of up to $\pm 40°$ relative to the Earth's equator.[5] The basic objective assumed for the ship deployment strategy was to position the ship 810 nm. downrange from the reentry point for all trajectories allowable under these ground rules (assuming the reentry flight path angle remains fixed at -6.0°).

The procedure used was to plot the locus of all allowable reentry points for each of several lunar declinations ranging over a complete lunar month. For each reentry point, a corresponding ship location point was plotted 810 nm. downrange. The locus of optimum ship position points that results can be closely approximated by a constant latitude line whose maximum length is 2000 nm., and whose latitude is the negative of the lunar declination at the time of lunar departure.[6]

The time of flight for the trans-Earth trajectory is expected to vary between about 84 and 110 hours. Within a relatively short period of tracking time following trans-Earth injection, it is expected that the reentry point will be known to within a few miles. Mid-course corrections can be expected to steer toward this point, and should assist, rather than handicap, ship deployment.

---

(5) "Apollo operational nominal trajectory ground rules," MSC Mission Planning and Analysis Division, July 2, 1965.

(6) "Communications and Tracking Coverage for the Reentry Phase of Apollo Lunar Missions," Bell Telephone Laboratories, Inc., March 10, 1964.

An assumed ship relocation distance has been taken to be 900 nm., corresponding to 72 hours of sailing time at 12.5 knots. This combination of time and speed allows at least 12 hours of tracking time to determine the location of the reentry point and a 2.5 knot derating of the ship's cruising speed. The length of the optimum ship position locus that can be covered is therefore 1800 nm., or 90% of the total allowable spread.

As a practical matter, one ship could provide good (but not necessarily optimum) coverage for 100% of all allowable trajectories under the assumptions made for this study, due to the following factors:

(1) For many days, the locus of optimum ship positions will be less than 2000 nm. long,

(2) the 10% gap as developed above need not be completely uncovered; it might merely subtract from the S-band coverage interval,

(3) due to spacecraft fuel limitations, it is expected that some inclination angles within the "allowable" spread will be very improbable, or even impossible, to attain for some days of the lunar month.

This study has also considered sensitivity to changes of the following factors:

(1) Altitude profiles different from Figure 5 (i.e., the other figures shown, plus others not shown in this memorandum having reentry flight path angles different from - 6.0°),

(2) time of lunar departure (i.e., the difference in time of actual departure from that planned when the ship took up its initial station),

(3) changes in planned landing site location, both before and after the mission has started.

Within the bounds of anticipated reasonable change, the results are relatively insensitive to these factors. In the interest of brevity the sensitivity analysis will not be discussed here; the "optimum" coverage potential of a single ship would not be expected to be reduced to below about 80% of the "allowable" trajectories, although the optimum downrange distance from the reentry point might change.

Since one ship can ideally cover almost all "allowable" trajectories, the question arises of the best use of a second ship if it were available. The following alternatives are suggested:

(1) Use the second ship to obtain optimum coverage for 100% of all "allowable" trajectories.

(2) Deploy the second ship further downrange from the reentry point to lengthen the time of contact. (Note that these two alternatives can often be realized simultaneously.)

(3) Bias the two ships to opposite sides of the expected trajectory to allow for longer coverage in the event of lateral deviations.

The chief value of the second ship appears to be its availability for adding to MSFN support as mission requirements change. For example, the second ship would be very desirable if any of the following requirements are added in the future:

(1) A longer reentry-to-touchdown range capability,

(2) coverage of an alternate, contingency landing area,

(3) simultaneous support of two missions.

In addition, the second ship will increase the probability of meeting the present requirements by being available as a back-up if the first ship fails.

VI. Conclusions and Recommendations

In the light of the present knowledge of the capabilities of the various systems used during the reentry and recovery phases of Apollo lunar missions, the following conclusions are made:

1. The direction finding technique planned by the recovery aircraft would not be sufficient by itself to provide a high probability of determining the CM landing point. The situation would be conderably worse if more than 7 db of charring loss occurs on the CM S-band antennas.

2. The USB system on the reentry ship does not have adequate capability to acquire the CM by itself to insure voice and TM communications with the CM while it is not in blackout.

3. The C-band tracking system of the reentry ship as presently planned is inadequate to perform plasma sheath tracking of the CM while it is in blackout. It is lacking in both range performance and in acquisition capability.

4. By adopting the modifications proposed by GSFC, the capability of the C-band radar system can be improved to permit it to serve as an acquisition aid to the USB system as well as providing gross impact point prediction data to the recovery force.

5. The Apollo Instrumented Aircraft do not have sufficient capability to warrant their deployment during the reentry phase.

6. A single reentry ship would be capable of providing optimum coverage for about 90% of the possible spread of reentry trajectories as presently planned. The optimum ship location would be about 800 nm. down range from the reentry point, and would provide up to two minutes of C-band tracking and one and one-half minutes of S-band communication coverage.

From the conclusions above, it is recommended that:

1. Proposed modifications of the C-band radar system on the reentry ship be carried out to improve the effectiveness of the reentry and recovery operations.

2. Apollo Instrumented Aircraft not to be used during the reentry phase.

R. K. Chen

J. E. Johnson

R. L. Selden

RKC
2021-JEJ-rc
RLS

Attached
Figures 1 - 8
Tables I - III
Appendix A

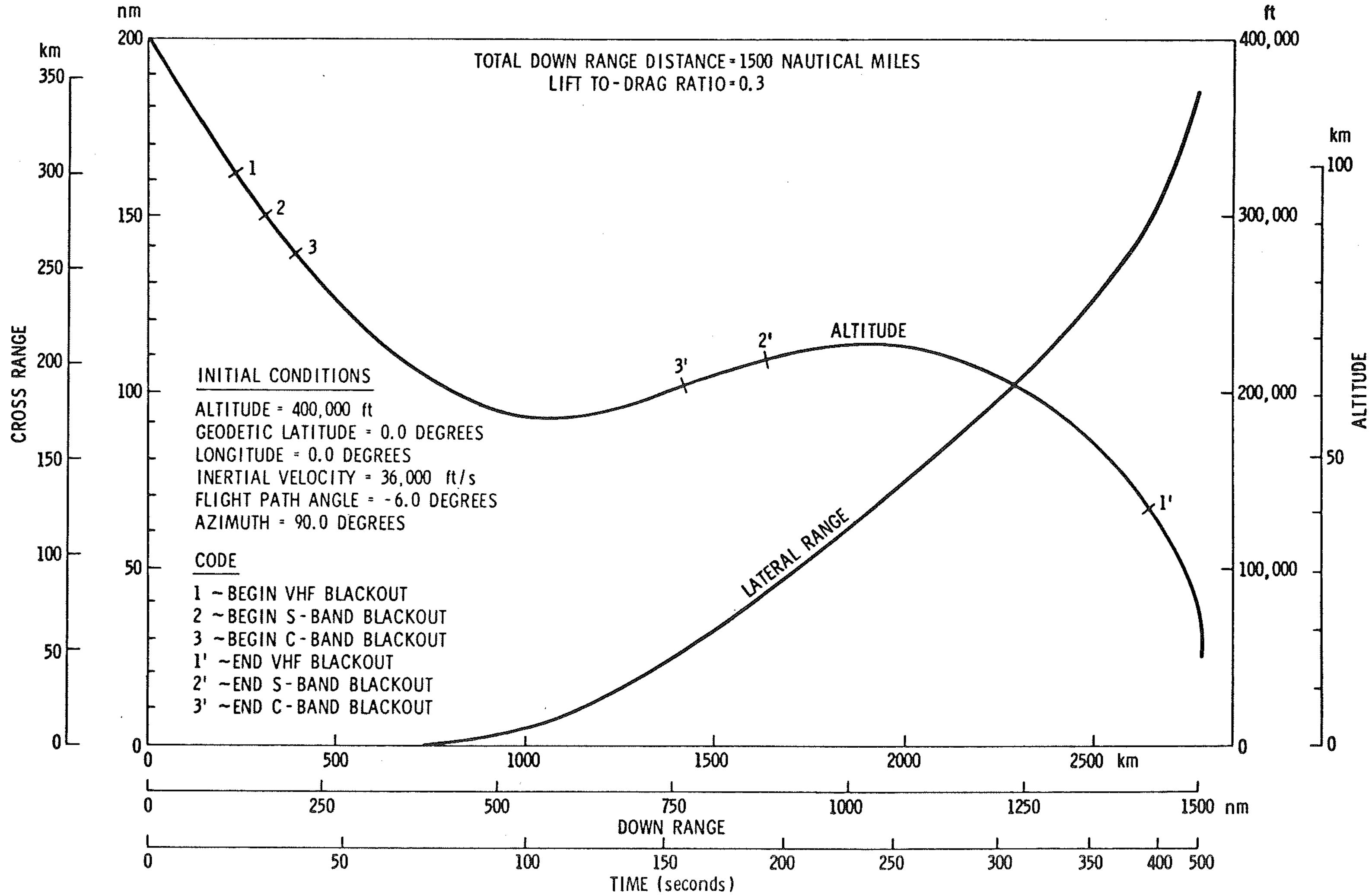

Figure 1 –Total down range distance =1500 nautical miles. Lift-to-drag ratio =0.3.

(Reference 1)

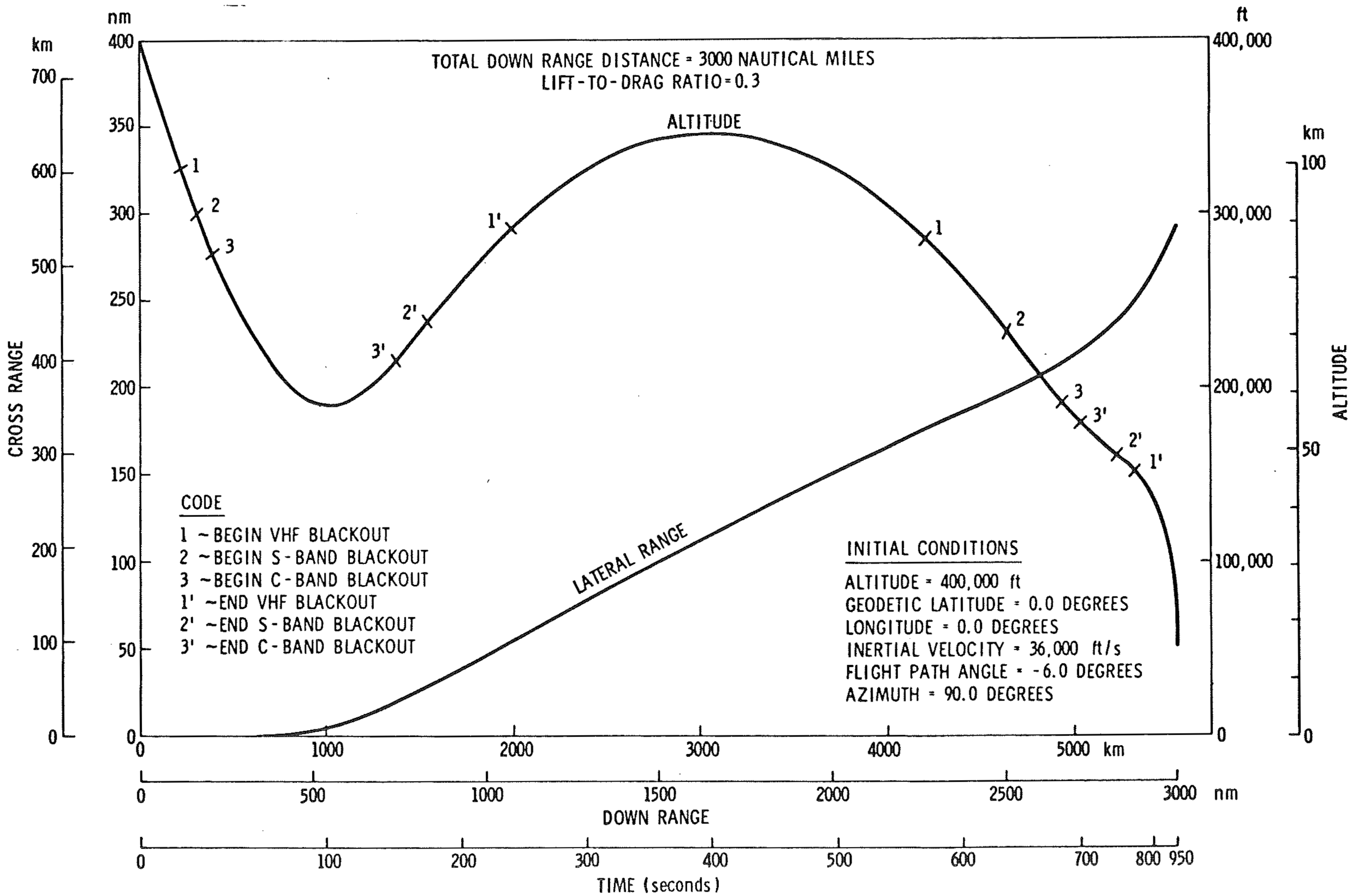

Figure 2 –Total down range distance = 3000 nautical miles. Lift-to-drag ration = 0.3.

(Reference 1)

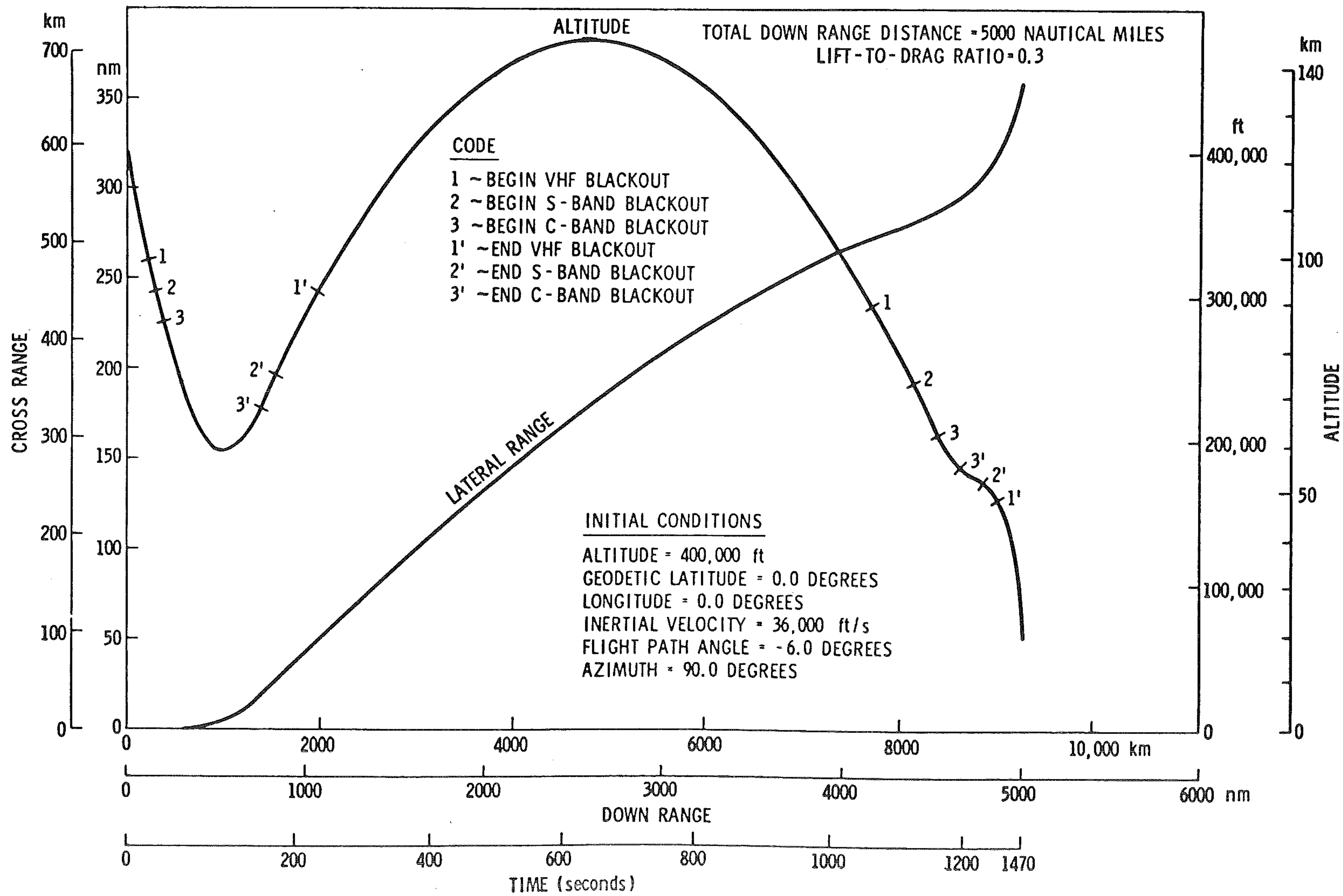

Figure 3 —Total down range distance = 5000 nautical miles. Lift-to-drag ratio = 0.3

(Reference 1)

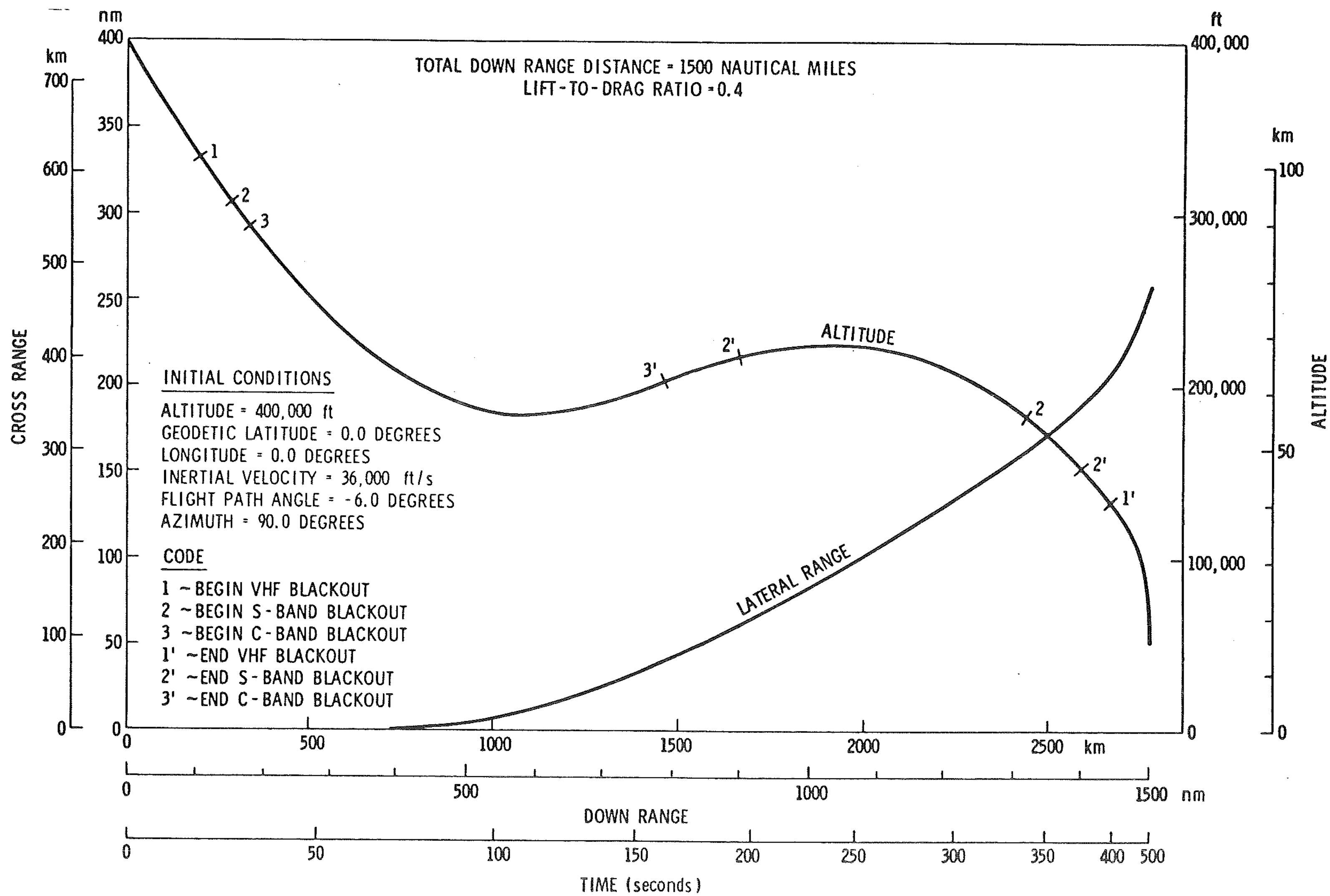

Figure 4 –Total down range distance = 1500 nautical miles. Lift-to-drag ratio = 0.4.

(Reference 1)

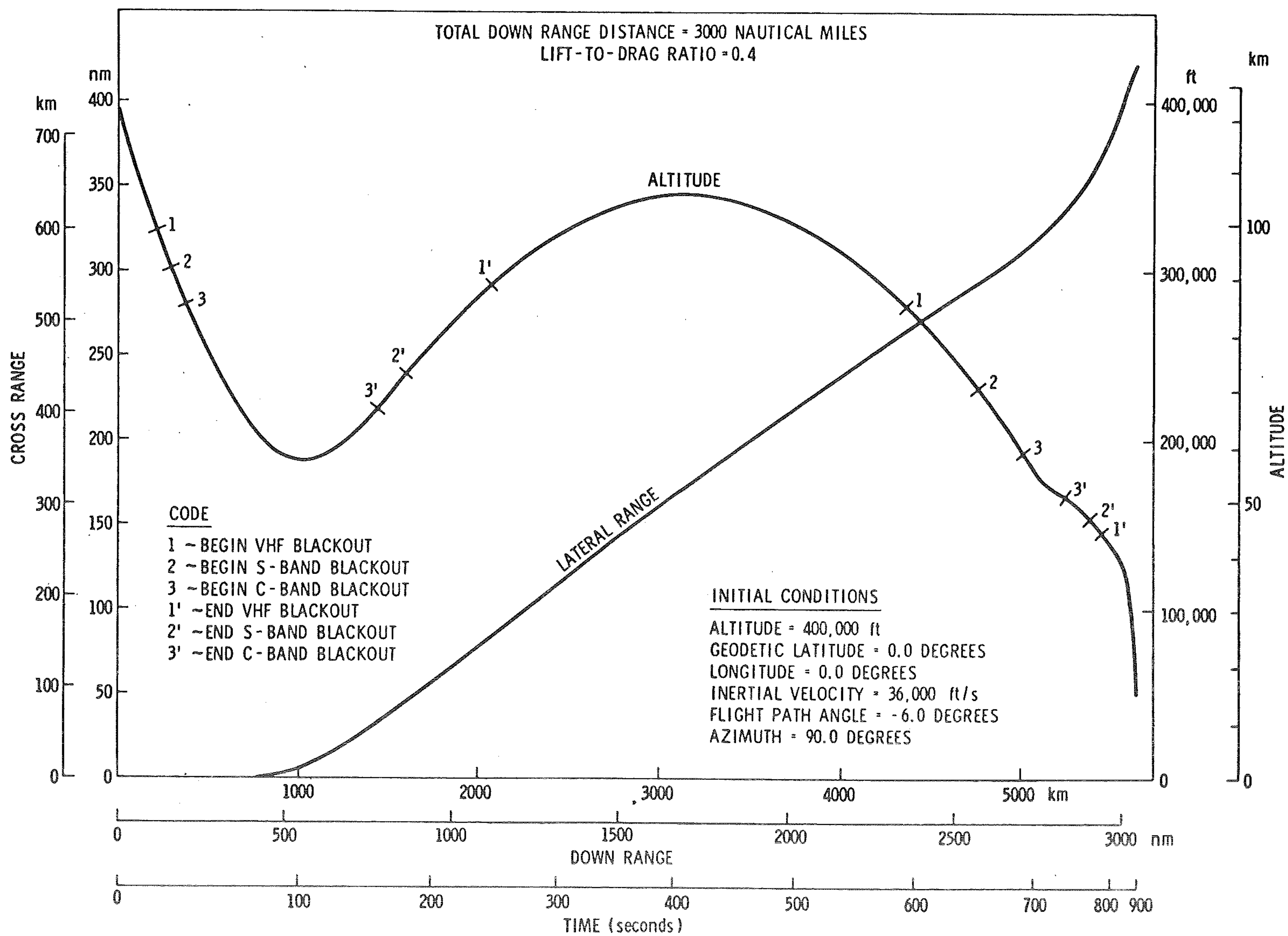

Figure 5 –Total down range distance = 3000 nautical miles. Lift-to-drag ratio =0.4.

(Reference 1)

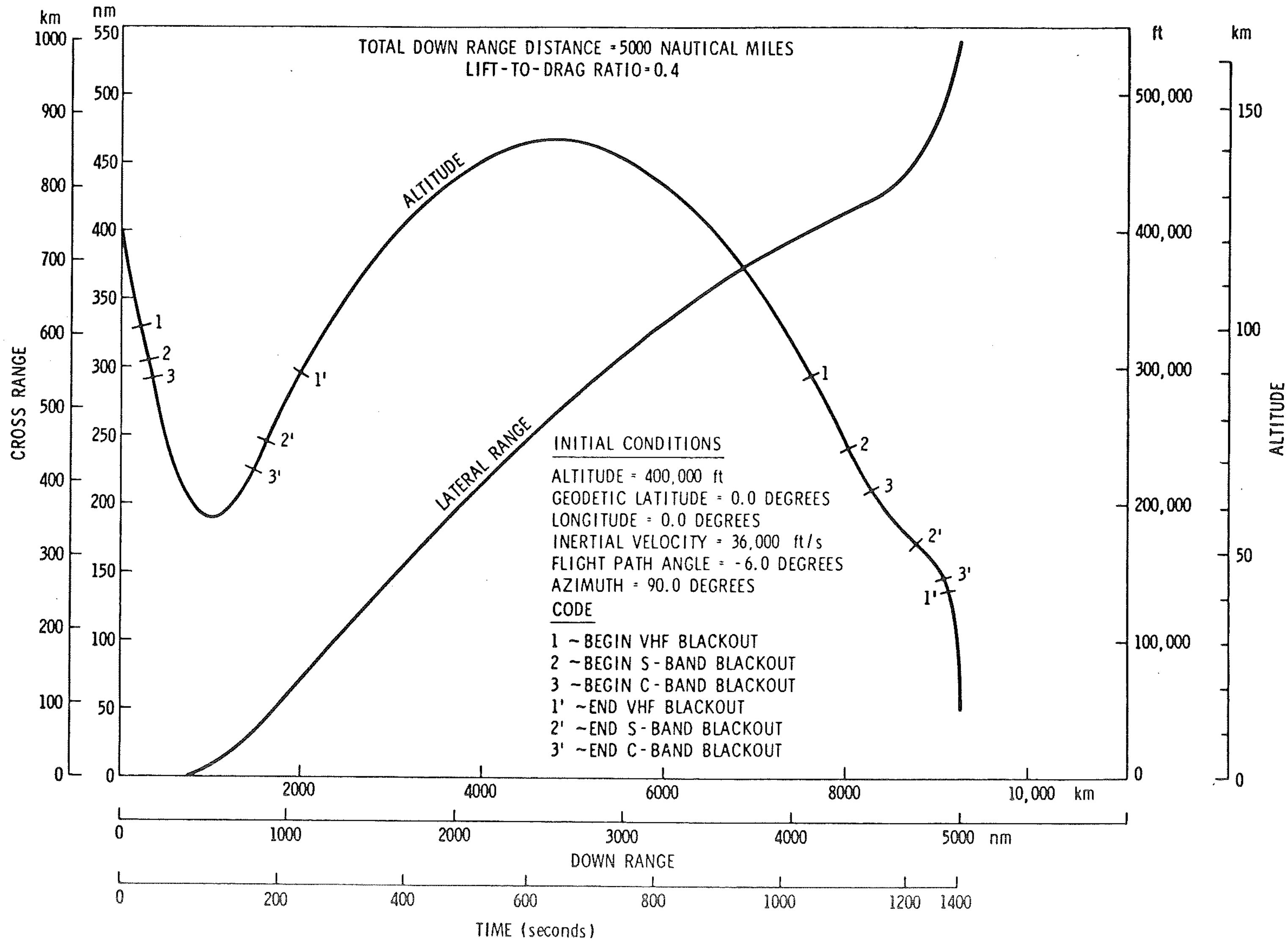

Figure 6 – Total down range distance = 5000 nautical miles. Lift-to-drag ratio = 0.4.

(Reference 1)

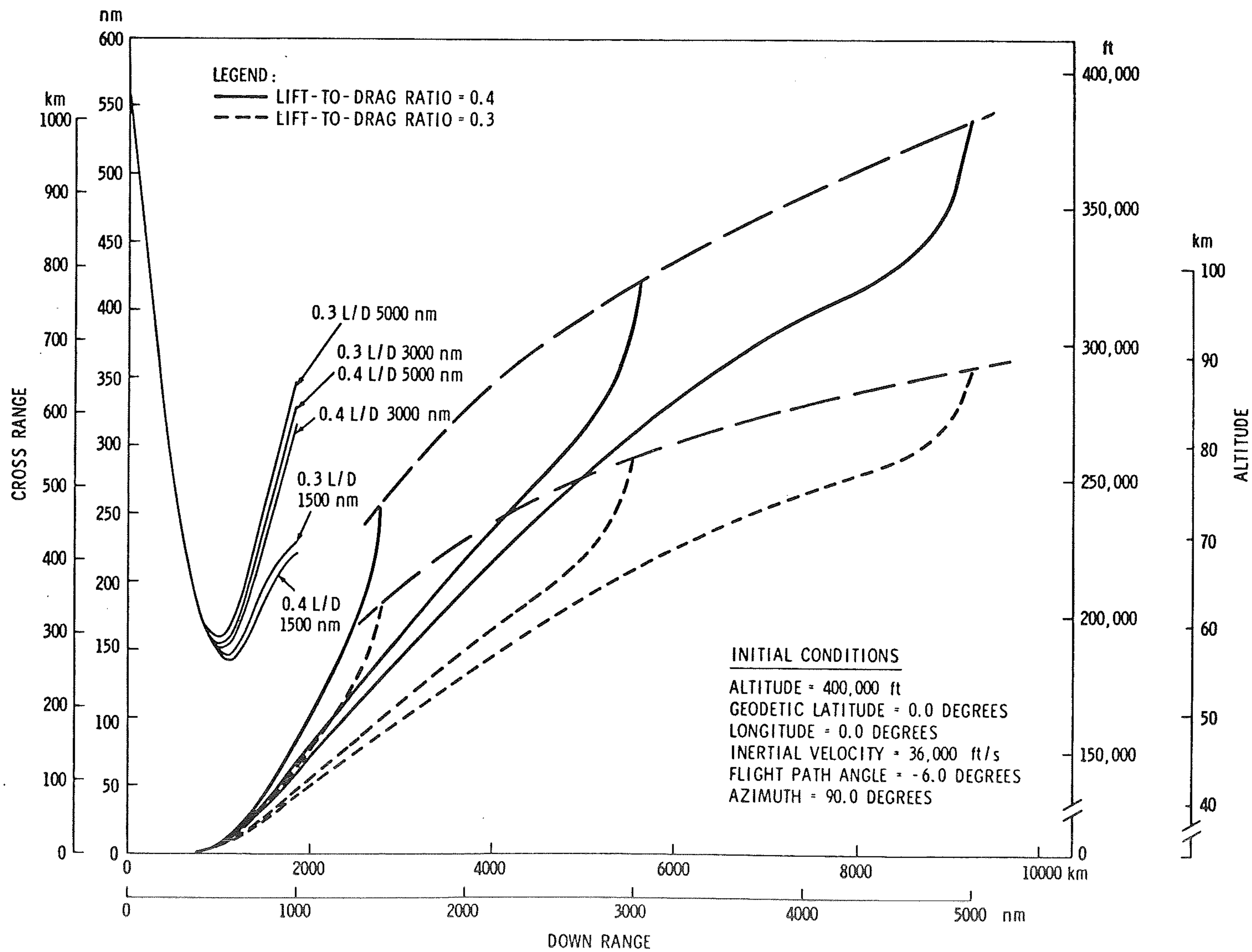

Figure 7

(Reference 1)

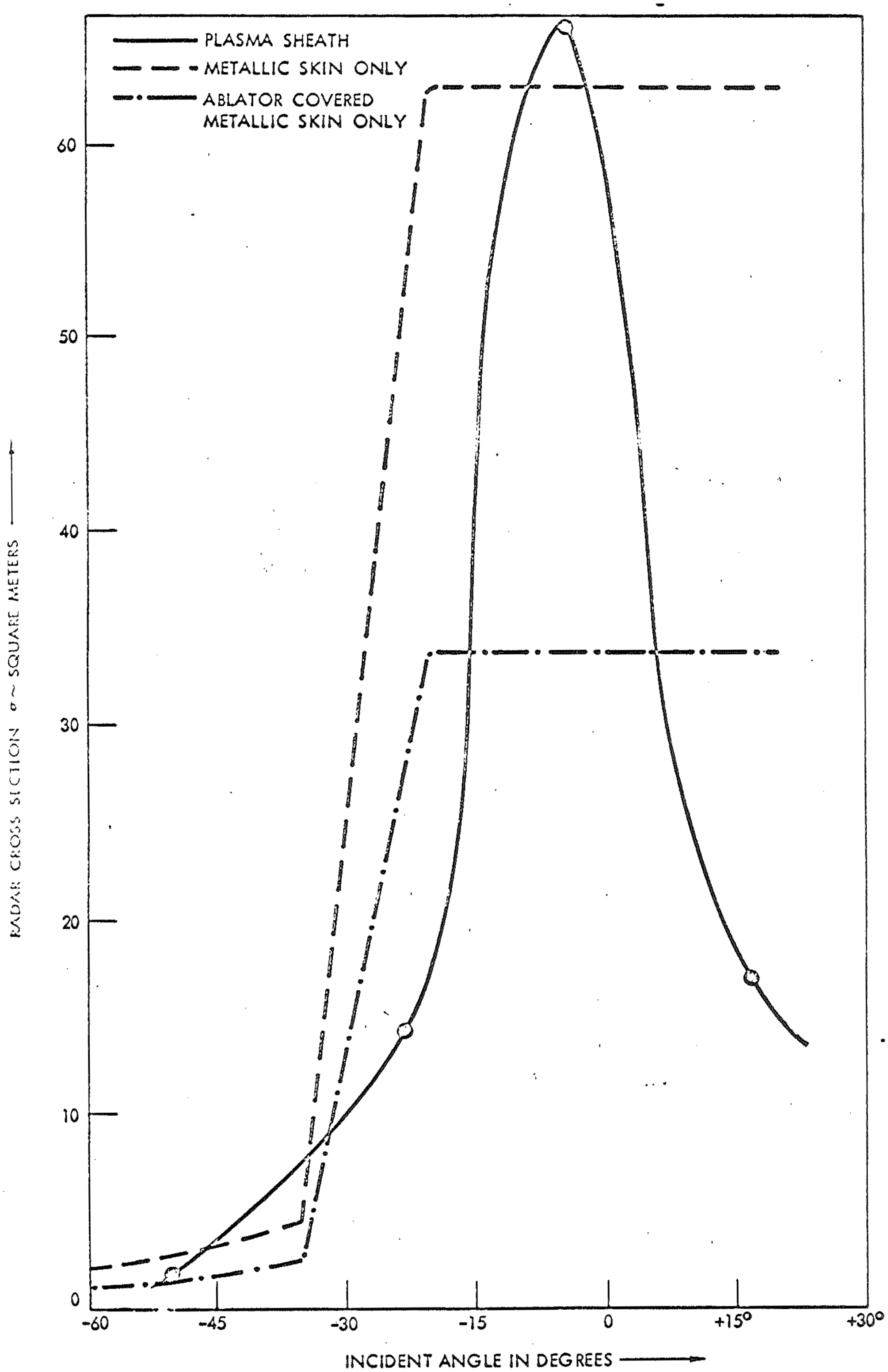

Figure 8 Average Cross Section of Capsule Reentry Sheath

(Reference 3)

TABLE I

Recovery Aircraft Performance for S-Band Frequency

Xmtr Power (CM)	13 dbw
Carrier Modulation Loss	-5 db
Ant. Gain	-0 db
RF Loss	-9 db
Effective Radiated Carrier Power	-1 dbw
Receiving Antenna Gain (A/C)	9 db
RF Loss	-1 db
Net Receiving Gain	8 db
Received Signal Power (0 Range)	7 dbw
Minimum Received Signal Required	-159 dbw
Range Loss Allowed	-166 db

log D = 30.4 db

D = 1100 nm. without charring

D = 500 nm. with 7 db charring

D = 35 nm. with 30 db charring

TABLE II

C-Band Radar FPQ-10 Performance (Estimated)
(Skin Track Mode)

$$4\,(R)_{dbnm} = (P_t)_{dbw} + 2(G)_{db} + 2\,(\lambda)_{dbcm} + (\sigma)_{dbm^2}$$
$$- (S/N)_{db} - (B)_{db} - (NF_o)_{db} - (L)_{db}$$

P_t	= 60 dbw (1Mw)		60
G	= 44 db (12 ft)	2(G) =	88
λ	= 7.5 dbcm (5.6 cm)	$2(\lambda)$ =	15
σ	= 0 dbm^2 ($1m^2$)		0
S/N	= 10 db		-10
B	= 62 db (1.6 mc)		-62
NF_o	= 5 db		-5
L	= 4 db		-4
4 R		=	82 db

R = 21 db = 126 nm. for $1m^2$ target.

= 23.5 db = 224 nm. for $10m^2$ target.

Where R = Range in nm.

P_t = transmitter power (peak) in watts

G = Antenna Gain

λ = Wavelength in cm

σ = target cross section in m^2

S/N = Signal to noise ratio

B = IF Bandwidth in CPS

NF_o = Receiver Noise Figure

L = System Losses

TABLE III

Proposed Modified FPQ-10 Performance (Estimated)
(Skin Track Mode)

$*P_t$	= 64.8 dbw (3Mw)		64.8
$*G$	= 46.5 db (16ft)	$2(G)$ =	93.0
λ	= 7.5 dbcm (5.6cm)	$2(\lambda)$ =	15
σ	= 0 dbm^2 ($1m^2$)		0
S/N	= 10 db		-10
B	= 62 db (1.6mc)		-62
$*NF_o$	= 2 db		- 2
L	= 4 db		- 4
$4(R)\ db_{nm}$		=	94.8 db

R = 23.7 db = 235 nm. for $1m^2$ target.

R = 26.2 db = 420 nm. for $10m^2$ target.

* Improvement

APPENDIX A

Unified S-Band System Communication Performance Summary During Reentry Phase Between Reentry Ships and CM

The following tables and general comments are the result of a quick look at the expected performance of the Apollo Unified S-Band (USB) System between reentry ships and the CM during the reentry phase of a lunar mission. In general when 30 db attenuation due to antenna charring is experienced all communications become marginal. If attenuation due to charring is 27 db, margins become slightly positive for a communications mode consisting of a full up link (data, voice, and ranging) and a full down-link low bit rate telemetry configuration (telemetry, voice, and ranging).

Summary of Re-entry Communications

1.0 Up Link Received Signal Level

Transmitted Power (2kw)	+33.0 dbw
Transmit circuit losses	-0.5 db
Antenna Gain (12')	+35.5 db
Path Loss (500 N. Miles)	-158.25 db
Polarization Loss	-0.1 db
Receive Antenna Gain	0 db
Antenna charring attenuation	-30.0 db
Receive circuit losses	-6.9 db
Total Received Signal	-127.25 dbw

2.0 Down - Link Received Signal Level

Transmitted Power (20w)	+13.0 dbw
Transmit circuit losses	-9.1 db
Antenna Gain	0 db
Antenna charring attenuation	-30.0 db
Path Loss (500 N. Miles)	-159.0 db
Polarization Loss	-0.1 db
Receive Antenna Gain (12')	+36.2 db
Receive circuit losses	-0.5 db
Total Received Signal	-149.5 dbw

3.0 Spacecraft Receiver Noise Spectral Density (N_o)

NF of System 13.5 db T= 6490°K 190.5 dbw/cps

4.0 Ship Receiver Noise Spectral Density (N_o) 204.0 dbw/cps

T= 290°K

5.0 Channel Signal Spectral Density Requirements (E/N_o)

Up-Voice	10db in 20Kc	53db/cps
Up-Data	10db in 20Kc	53db/cps
Up-Carrier	12db in 700 cps	40.5db/cps
Down-Link Telemetry	1.6KBPS BER 10^{-6}	46.0db/cps
	1.6KBPS BER 10^{-3}	42.4db/cps
Down-Link Voice	Desired 8db in 20KC	51.0db/cps
	Minimum 5db in 20KC	48.0db/cps
Down-Link Carrier	12db in 50cps	29.0db/cps

Turned-Around PRN Ranging (60 seconds) (WER 10^{-3}) 32.0db/cps

Back-up voice 42.0db/cps

6.0 Performance Margins

6.1 Full Up-Link

Channel	Char Attenuation	Margin
Up-Voice	30db	+2.2db
Up-Data	30db	-0.7db
Ranging	30db	------
Up-Carrier	30db	+18.0db
Up-Voice	27db	+4.0db
Up-Data	27db	+1.1db
Ranging	27db	------
Up-Carrier	27db	+21db

6.2 Down-Link

Channel	Up Link Mode	Char Attenuation	Margin
Telemetry	Full	30db	-3.1db
Voice	Full	30db	-1.1db
Ranging	Full	30db	-5.6db
Carrier	Full	30db	+20.4db
Telemetry	Full	30db	+6.1db
Ranging	Full	30db	-7.8db
Carrier	Full	30db	+18.0db

6.2 Down Link Performance Margins (Con't)

Channel	Up Link Mode	Char Attenuation	Margin
Telemetry	N/A	30db	-1.6db
Voice	N/A	30db	-0.6db
Carrier	N/A	30db	+20.9db
Telemetry	N/A	30db	+3.1db
Back-up Voice	N/A	30db	+5.2db
Carrier	N/A	30db	+19.7db
Ranging	Ranging Only	30db	+8.85db
Carrier	Ranging Only	30db	+22.0db
Telemetry	Full	27db	+0.8db
Voice	Full	27db	+1.8db
Ranging	Full	27db	+2.7db
Carrier	Full	27db	+23.4db

7.0 General

7.1 Changing the up-link to voice and ranging only when antenna charring attenuation is 30db, will improve the up-link voice margin approximately +2.0db, however, the ranging margin will be degraded about 3.0db.

7.2 Range code acquisition times for the margins shown above are as follows:

Range Code Margin	Code Acquisition Time (WER 10^{-3})
0db	60 seconds
-7.8db	470 seconds
-5.6db	240 seconds
+8.8db	9 seconds
+2.7db	20 seconds

7.3 The margin data presented above is based on the current estimates of spacecraft parameters as defined in NAA revision B S-Band circuit margins (preliminary), except assumption is made here that the S-band omni-antenna elements are switched individually rather than in pairs, and GSFC's estimate of MSFN ground station performance.